

Changes in Holocene ostracode faunas and depositional environments in the Kitan Strait, southwestern Japan

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Received 16 October 2001; Revised manuscript accepted 21 December 2001

Abstract. At least 106 species were identified from 36 samples obtained from two cores (T1 and T2), which were recovered from the Kitan Strait off Wakayama City, southwestern Japan. Q-mode cluster analysis of cores T1 and T2 revealed three biofacies (PL, PT and LS). Changes in depositional environments based on the observed distribution of ostracodes were analysed, and the following sequence is proposed. Before ca. 7,000 cal yr BP, the T1 site was a sandy coast, ranging from an outer bay to the open sea, close to a river mouth, at water depths of more than 15–20 m, while the T2 site ranged from a bay coast to an outer bay, close to a river mouth, at water depths of less than 15–20 m. During ca. 7,000–2,000 cal yr BP, the position of the sites fell within ranging an outer bay to the open sea at water depths of 30–40 m influenced by residual and/or tidal currents from the straits. After ca. 2,000 cal yr BP, the sites were situated on a sandy coast, ranging from an outer bay to the open sea, close to a river mouth, at water depths of more than 15–20 m. Two new species, *Trachyleberis ishizakii* and *Cytheropteron kumaii*, are also described.

Key words: depositional environments, Holocene, Kitan Strait, Ostracoda, Wakayama

Introduction

Fossil ostracodes have frequently been used to elucidate the way in which the environment of deposition changes with time (e.g., Ishizaki *et al.*, 1993; Cronin *et al.*, 1994; Irizuki *et al.*, 1998b), because they are highly sensitive indicators of several environmental factors (e.g., Ishizaki and Irizuki, 1990; Ikeya and Suzuki, 1992; Yamane, 1998; Yasuhara and Irizuki, 2001). However, little studies of Japanese Holocene ostracodes have been carried out (Frydl, 1982; Ishizaki, 1984; Ota *et al.*, 1985; Ikeya *et al.*, 1987; Ikeya *et al.*, 1990; Iwasaki, 1992; Kamiya and Nakagawa, 1993; Irizuki *et al.*, 1998a; Miyahara *et al.*, 1999; Irizuki *et al.*, 2001). Many of these studies concentrate on temporal changes of Holocene ostracode assemblages in small drowned valleys and enclosed bays. Irizuki *et al.* (1998a) elucidated paleoenvironmental changes on the western coast of the Miura Peninsula, central Japan on the basis of numerical analyses of ostracode distributions. Miyahara *et al.* (1999) and Irizuki *et al.* (2001) used sedimentary facies

from cores, containing fossil ostracodes and high density radiocarbon dating to construct a relative sea-level curve and to discuss paleoceanic changes in the Osaka area, southwestern Japan.

The Kitan Strait is situated between Osaka Bay and the open sea. The area provides an important record of the depositional environments of the Seto Inland Sea and Osaka Bay, and therefore yields key data for inferring paleoceanic conditions.

This study aimed to elucidate ostracode faunas and the temporal change in depositional environments off the western coast of Wakayama City, near the Kitan Strait. We also discuss the consequences of sea-level changes in Osaka Bay and the study area.

Locality, lithofacies and methodology

Drilling cores (T1 and T2) were excavated by the National Institute of Advanced Industrial Science and Technology from the Kitan Strait (T1: 34°14.7' N, 135°5.2' E, 19.61 m

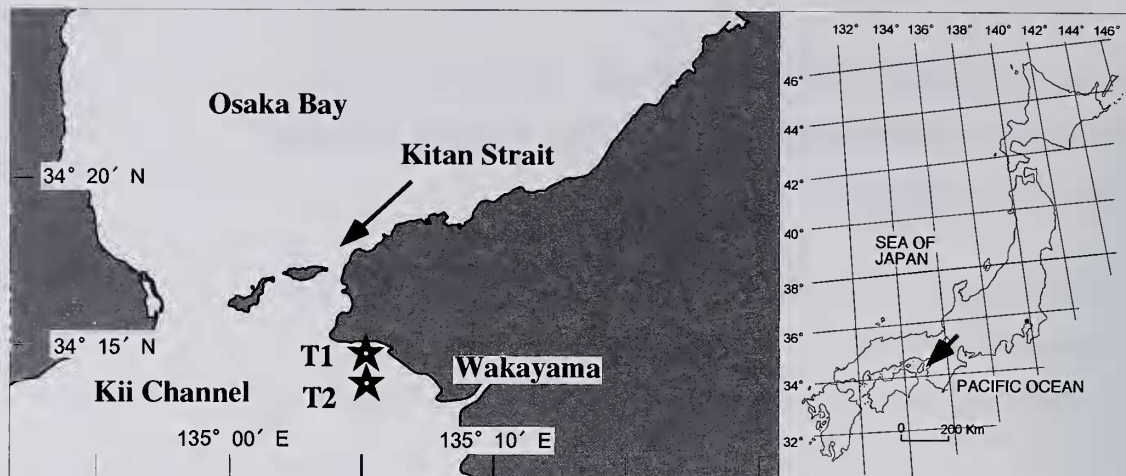


Figure 1. Index and locality maps.

water depth; T2: 34°14.5' N, 135°5.2' E, 24.78 m water depth) off Wakayama City, southwestern Japan (Figure 1). Nanayama *et al.* (1999) described in detail the Holocene and upper Pleistocene sequences in cores T1 and T2. We briefly mention those sequences here (Figure 2). Sediments at altitudes lower than -33.5 m in core T1 and -38.3 m in core T2 consist of sand and gravel, and the enclosing matrix is coarse sand. Sediments at altitudes between -19.6 and -33.5 m in core T1 and between -24.8 and -38.3 m in core T2 consist of alternating beds of fine to medium sand layers and silt layers with shell fragments, showing intensive bioturbation. Nanayama *et al.* (1999) reported two layers of debris flow deposits (Df1 and Df2). Df1 is situated at altitudes of approximately -24.1 to -24.3 m in core T1 and -29.3 to -30.4 m in core T2 (Figure 2). Df2 is situated at altitudes of approximately -27.2 to -27.7 m in core T1 and -34.5 to -35.7 m in the core T2 (Figure 2). Volcanic glasses are concentrated at an altitude of approximately -31 m in core T2. Nanayama *et al.* (1999) reported that these volcanic glasses are correlated with the Kikai-Akahoya (K-Ah) volcanic ash, dated at ca. 7,300 cal yr BP (Fukusawa, 1995).

Samples of the sediment core, each approximately 5 cm thick, were immersed in water, boiled for about one hour on a hot plate, washed through a 75 μm sieve and then dried. Dry weights were calculated from the original sample weight, scaled by the percentage water content of each sample. The fraction coarser than 200 μm was sieved to allow the ostracode fauna to be determined, and for specimens of each taxon to be obtained. Samples containing abundant ostracode specimens were divided using a sample splitter into workable aliquots of approximately 100–200 specimens. In the remaining samples, all the specimens present were picked. The number of specimens refers to

the estimated minimum number of carapaces present in each sample, determined by taking the total number of left or right valves, whichever was the greater.

Ostracode biofacies

At least 106 ostracode species were identified from 36 samples obtained from cores T1 and T2 (Appendix). A selection of these species is illustrated in Figure 3.

Q-mode cluster analysis was used to examine vertical changes in ostracode faunas and to determine ostracode biofacies, which would closely reflect variations in the depositional environment. Taxa represented by three or more specimens in any one sample were used for analysis (some *Aurila* and *Pontocythere* species groups are expressed collectively as "spp."), and each sample contained more than 50 specimens. Horn's overlap indices (Horn, 1966) were used to assess similarities, and clustering was achieved by the unweighted pair-group arithmetic average method. The results revealed three biofacies (PL, PT and LS; Figure 4). To interpret these biofacies reflecting depositional environments, we referred to the distributions of present-day dead ostracode shells, because many studies of the distributions of present-day ostracodes have been based on dead ostracode shells.

Figures 5 and 6 show the stratigraphic positions of biofacies and percentages of 24 taxa dominating each of the biofacies in these cores.

(1) *Biofacies LS* (*Loxoconcha viva*-*Spinileberis quadriaculeata* biofacies).—Biofacies LS is composed of seven samples and lies in the middle part of cores T1 and T2. It is characterized by the dominance of *Loxoconcha viva* Ishizaki, *Spinileberis quadriaculeata* (Brady) and *Cytheropteron kumaii* sp. nov. (= *Cytheropteron miurense* of Ikeya

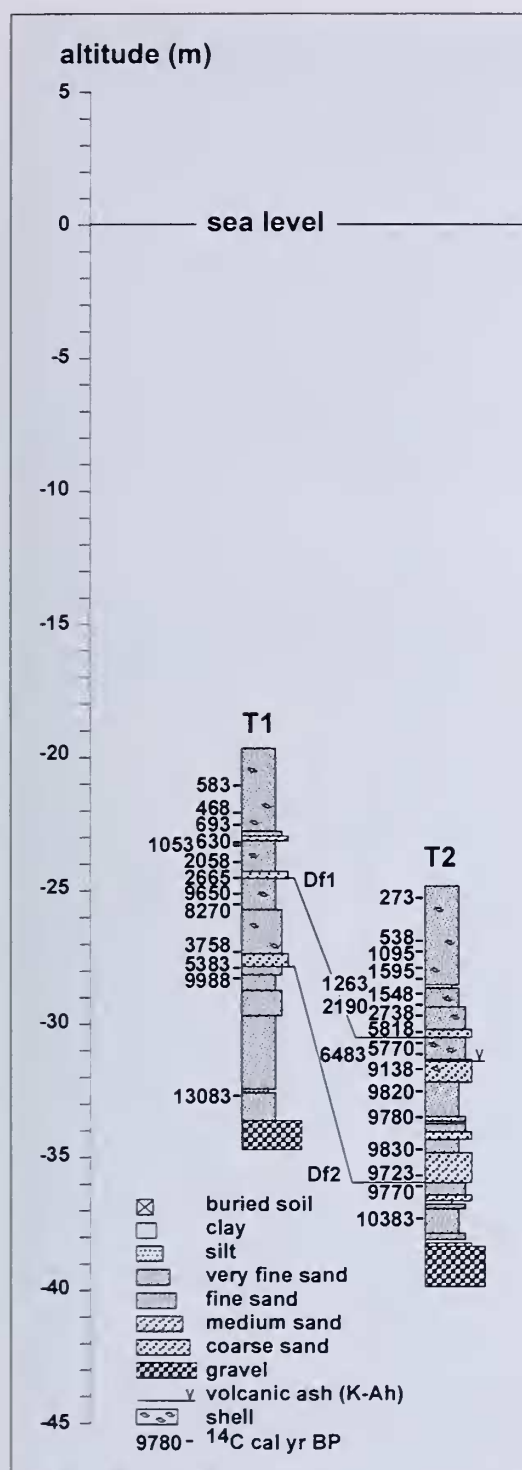


Figure 2. Columnar sections of T1 and T2 cores and horizons of radiocarbon age (cal yr BP). Radiocarbon ages calibrated and columnar sections modified from Nanayama *et al.* (1999).

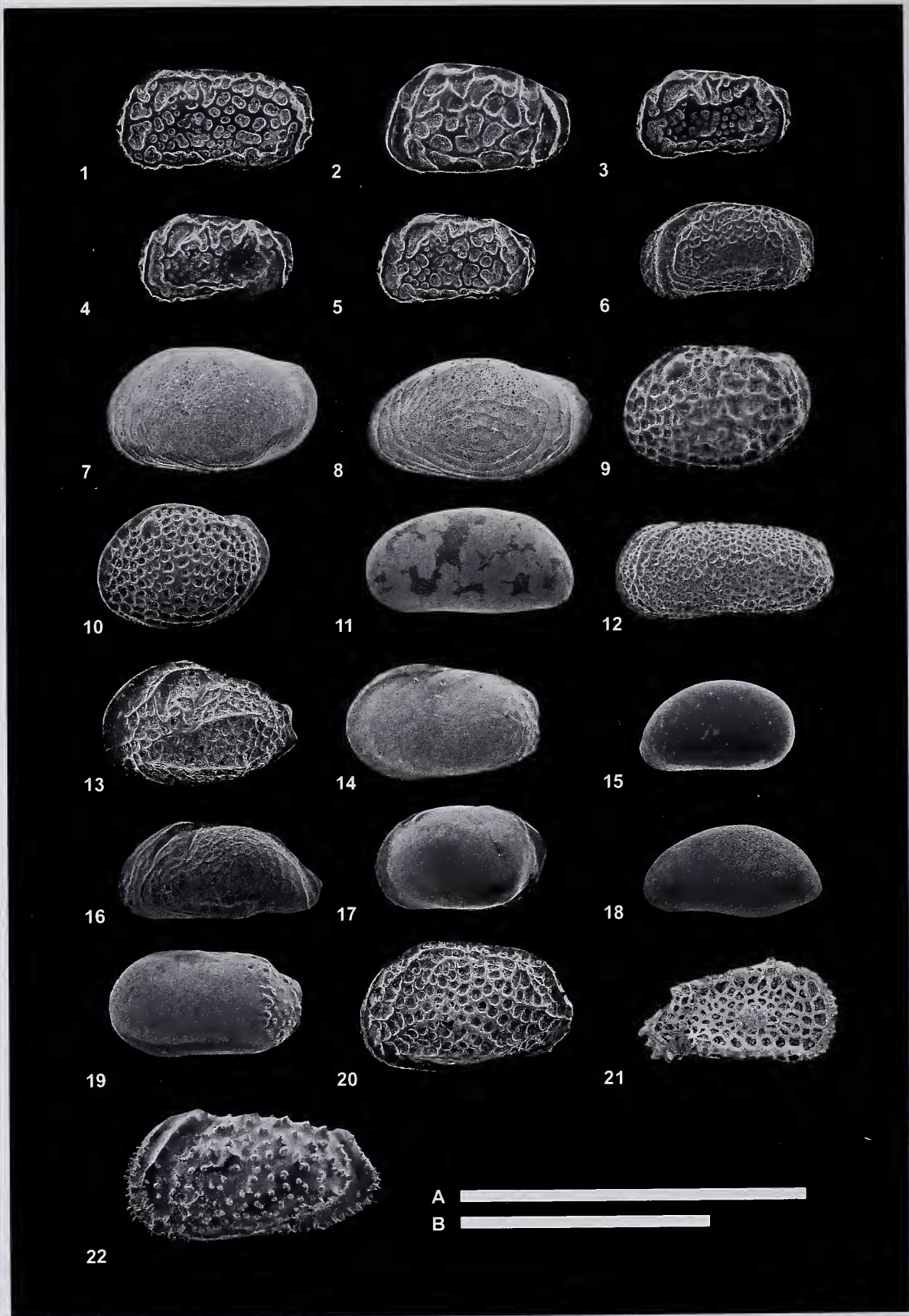
and Itoh, 1991 and *Cytheropteron* sp. of Yasuhara and Irizuki, 2001). *Ambtonia obai* (Ishizaki), *Falsobuntonia hayamii* (Tabuki), "form A" (Abe and Choe, 1988) of *Bicornucythere bisanensis* (Okubo), *Aurila spinifera* Schornikov and Tsareva s.l., *Krithe japonica* Ishizaki, *Kobayashiina donghaiensis* Zhao and *Amphileberis nipponica* (Yajima) are also common.

L. viva is abundant at water depths of 15–37 m in Tateyama Bay, central Japan (Frydl, 1982). *S. quadriaculeata* is common in most areas of Osaka Bay and Hiuchinada Bay (Yasuhara and Irizuki, 2001; Yamane 1998). *C. kumaii* is reported from the outer part of Sendai Bay near the open sea at water depths of more than 50 m (Ikeya and Itoh, 1991) and from Osaka Bay at water depths of 37.2 m (Yasuhara and Irizuki, 2001). *Falsobuntonia* (*hayamii* and *taiwanica* Malz) is commonly found in the open sea off Shimane at water depths of more than 50 m (Ikeya and Suzuki, 1992). *A. obai* is abundant at water depths of 20–40 m (e.g., Ishizaki, 1971; Frydl, 1982; Bodergat and Ikeya, 1988). *A. spinifera* s.l. is reported from the sandy part of Hiuchi-nada Bay near the Kurushima Strait (Yamane, 1998) and from the sandy part of Osaka Bay at a water depth of 37.2 m, where the influence of residual and/or tidal currents from the Akashi Strait is apparent (Yasuhara and Irizuki, 2001). *K. japonica*, *Ko. donghaiensis* and *A. nipponica* are common at water depths of more than 15–20 m in shallow sea areas around Japan (e.g., Yasuhara and Irizuki, 2001; Yamane, 1998; Bodergat and Ikeya, 1988; Frydl, 1982; Ishizaki, 1971).

The distribution of species suggests that biofacies LS is interpreted as ranging from an outer bay to the open sea at a water depth of 30–40 m, under the influence of residual and/or tidal currents from the strait.

(2) *Biofacies PT* (*Pontocythere* spp.-*Trachyleberis scabrocuneata* biofacies).—Biofacies PT is composed of two samples and lies in the lower part of core T2. It is characterized by the dominance of *Pontocythere* spp., *Trachyleberis scabrocuneata* (Brady), *S. quadriaculeata* and *Loxococoncha uranouchiensis* Ishizaki, with smaller numbers of *Loxococoncha pulchra* Ishizaki and *Nipponocythere bicarinata* (Brady). Intertidal and phytal species (*Aurila* spp. except *A. munechikai* and *A. spinifera* s.l., *Australimoosella tomokoae*, *Cornucoquimba tosaensis*, *Hemicytherura* spp., *Loxococoncha* spp. except *L. optima*, *L. pulchra*, *L. tosaensis*, *L. uranouchiensis* and *L. viva*, *Neonesidea oligodentata*, *Paradoxostomatidae* spp., *Pseudoaurila japonica*, *Robustaurila* spp., *Sclerochilus* sp., *Semicytherura* spp. and *Xestoleberis* spp.) are also common.

Pontocythere spp. are found in a range of habitats, from the sandy coasts of outer bays to open sea areas and/or river mouths (e.g., Ishizaki, 1968; Ikeya and Hanai, 1982; Yamane, 1998). *T. scabrocuneata* is abundant in middle to outer bay regions (Yasuhara and Irizuki, 2001). *L.*



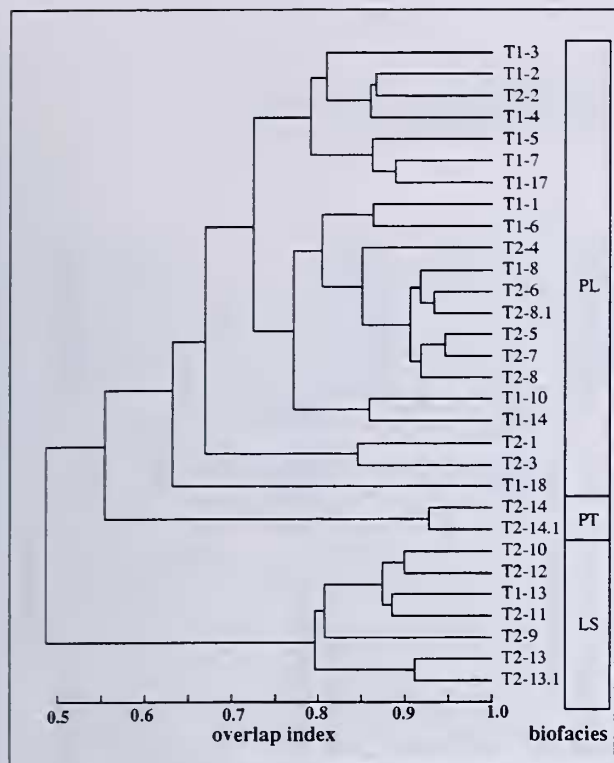


Figure 4. Dendrogram from Q-mode cluster analysis. PL, PT and LS represent the three biofacies found.

uranouchiensis is common in sandy bay coasts and abundant at water depths of less than 10 m (Frydl, 1982). *L. pulchra* is an estuarine inhabitant of Hiuchi-nada Bay, Seto Inland Sea, western Japan, that prefers low salinity and a water depth of less than 4 m (Yamane, 1998). *N. bicarinata* is common at water depths of more than 15 m in Osaka Bay (Yasuhara and Irizuki, 2001). However, species common at water depths of more than 15–20 m in shallow sea areas around Japan (e.g., *K. japonica*, *Ko. donghaiensis*, *A. nipponica*) are either rare or absent in this biofacies. Intertidal and phytal species could have been transported to this area by wave action or coastal currents.

Thus, biofacies PT is interpreted as ranging from a bay coast to an outer bay, near a river mouth, with water depths

of less than 15–20 m.

(3) *Biofacies PL* (*Pontocythere* spp.—*Loxoconcha optima* biofacies).—Biofacies PL is composed of 21 samples and lies in the upper part of cores T1 and T2, and also in the lower part of the T1 core. It is characterized by the dominance of *Pontocythere* spp., *Loxoconcha optima* Ishizaki, *L. pulchra* and intertidal and phytal species. *K. japonica*, *Ko. donghaiensis* and *A. nipponica* also occur in this biofacies.

L. optima is reported from a sandy coast, ranging from an outer bay to the open sea (Ishizaki, 1968). Those species which are common in biofacies LS, such as *C. kumaii*, *A. obai* and *F. hayamii*, are either rare or completely absent.

Biofacies PL is therefore interpreted as a sandy coast, ranging from an outer bay to the open sea, near a river mouth at water depths of more than 15–20 m, but shallower than biofacies LS.

Temporal changes of depositional environments

Radiocarbon dating was conducted using 31 samples from cores T1 and T2 (Nanayama *et al.*, 1999). We calibrated these radiocarbon ages using INTCAL98 (Stuiver *et al.*, 1998), because this was not done in the original study. Many of the radiocarbon ages in core T1 were reversed (Figure 6): we therefore used the radiocarbon ages from core T2 to date temporal changes in depositional environments. Correlations between cores T1 and T2 are based on Nanayama *et al.* (1999).

Based on the results of Q-mode cluster analysis, vertical changes in depositional environments and associated ostracode faunas in these cores are distinguished as follows:

Before ca. 7,000 cal yr BP.—This period is represented by biofacies PT, composed of two samples in core T2 (T2-14 and 14.1), and the lower part of biofacies PL, composed of three samples in core T1 (T1-14, 17 and 18).

It is considered that during this period the T2 drilling site ranged from a bay coast to an outer bay, near a river mouth, with water depth shallower than 15–20 m. At the same time, the T1 site was on the sandy coast, ranging from an

Figure 3. Scanning electron micrographs of fossil ostracodes from drilling cores in the Kitan Strait off Wakayama City. Scale bars = 1.0 mm (A for 1–19; B for 20–22). All specimens are adult left valves, except one specimen in Fig. 4.21 (an adult right valve). 1. *Callistocythere hayamensis* Hanai (sample no. T1-8). 2. *Callistocythere alata* Hanai (sample no. T1-6). 3. *Callistocythere asiatica* Zhao (sample no. T2-3). 4. *Callistocythere undata* Hanai (sample no. T2-4). 5. *Callistocythere* sp. 1 (sample no. T2-8). 6. *Ishizakiella miurensis* (Hanai) (sample no. T2-3). 7. *Loxoconcha pulchra* Ishizaki (sample no. T1-8). 8. *Loxoconcha optima* Ishizaki (sample no. T1-8). 9. *Loxoconcha tosaensis* Ishizaki (sample no. T1-6). 10. *Loxoconcha viva* Ishizaki (sample no. T2-8.1). 11. *Parakrithella pseudadonta* (Hanai) (sample no. T1-6). 12. *Cytheromorpha acupunctata* (Brady) (sample no. T1-6). 13. *Spinileberis quadriaculeata* (Brady) (sample no. T2-13.1). 14. *Falsobuntonia hayamii* (Tabuki) (sample no. T2-9). 15. *Xestoleberis opalescens* Schornikov (sample no. T2-3). 16. *Perissocytheridea* sp. (sample no. T2-2). 17. *Phlyctocythere japonica* Ishizaki (sample no. T2-14). 18. *Neopellucistoma inflatum* Ikeya and Hanai (sample no. T2-2). 19. *Ambtonia obai* (Ishizaki) (sample no. T2-12). 20. *Aurila spinifera* s.l. Schornikov and Tsareva (sample no. T2-13). 21. *Cletocythereis* sp. (sample no. T2-6). 22. *Trachyleberis scabrocuneata* (Brady) (sample no. T1-7).

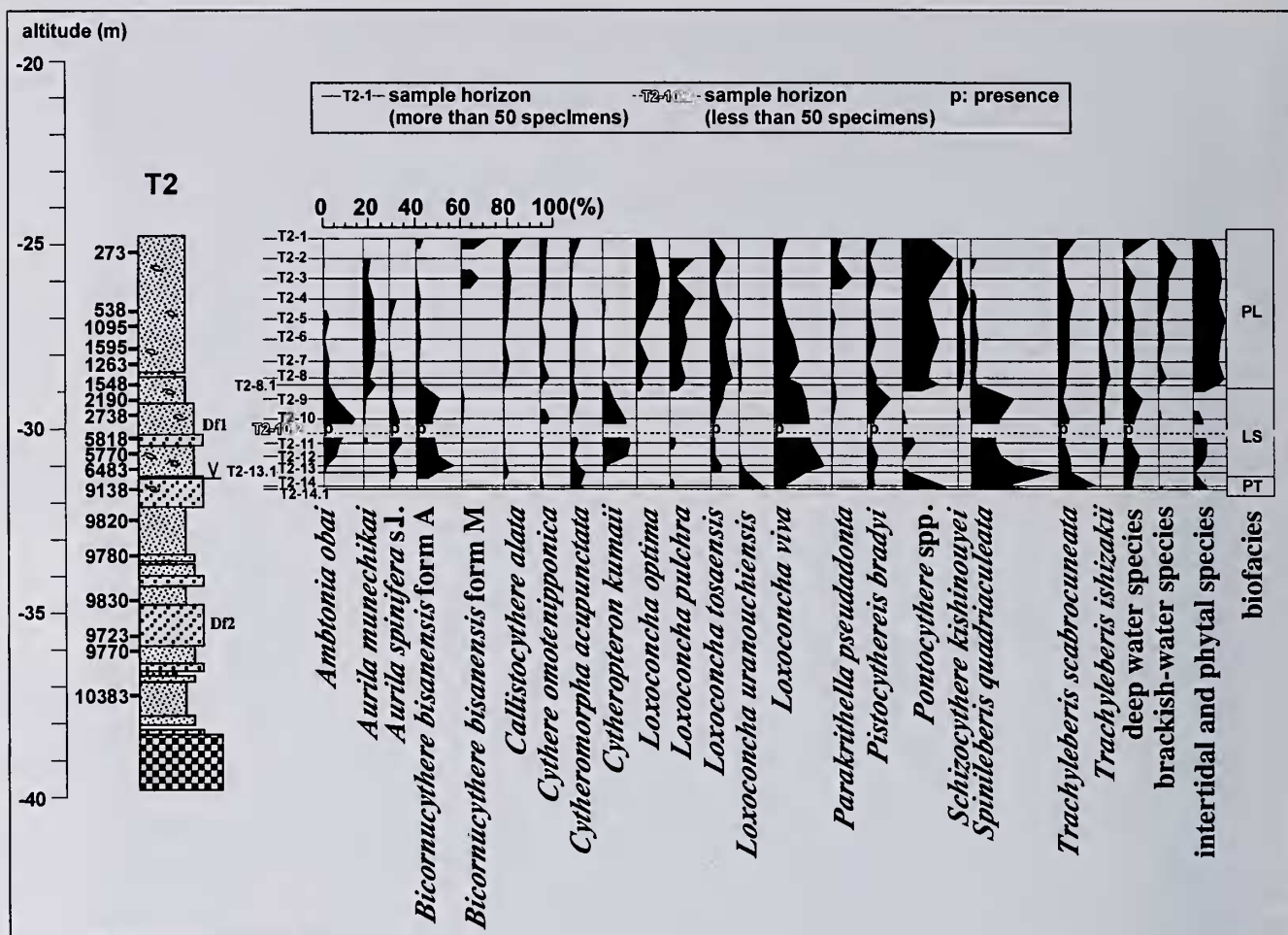


Figure 5. Columnar section of core T2, sample horizons, radiocarbon ages (cal yr B.P.), biofacies and percentages of dominant ostracode species. Deep-water species are *Amphileberis nipponica*, *Falsobuntonia hayamii*, *Kobayashiina donghaiensis*, *Kriithe japonica* and *Nipponocythere bicarinata*. Brackish water species are *Cytherura miii*, *Darwinula* sp., *Ishizakiella miurensis*, *Perissocythereida japonica*, *Perissocythereida* sp., *Spinileberis furuyaensis* and *Spinileberis pulchra*. Intertidal and phytal species are *Aurila* spp. except *A. munechikai* and *A. spinifera* s.l., *Australimosella tomokoae*, *Cornucoquimba tosaensis*, *Hemicytherura* spp., *Loxoconcha* spp. except *L. optima*, *L. pulchra*, *L. tosaensis*, *L. uranouchiensis* and *L. viva*, *Neonesidea oligodentata*, *Paradoxostomatidae* spp., *Pseudoaurila japonica*, *Robustaurila* spp., *Sclerochilus* sp., *Semicytherura* spp. and *Xestoleberis* spp.

outer bay to the open sea, near a river mouth, with water depths of more than 15–20 m. Species that are common at water depths of more than 15–20 m in shallow sea areas around Japan (e.g., *A. obai*, *K. japonica*, *Ko. donghaiensis* and *A. nipponica*) are, however, absent in samples T1-17 and T1-18. In these horizons, it is considered that water depths were shallower than the other horizons.

Ca. 7,000–2,000 cal yr BP.—This period is represented by biofacies LS, and is composed of six samples in core T2 (T2-9, 10, 11, 12, 13 and 13.1), and one sample in core T1 (T1-13).

These sites ranged from an outer bay to the open sea at water depths of 30–40 m, and were influenced by residual and/or tidal currents from the strait.

After ca. 2,000 cal yr BP.—This period is represented by biofacies PL and is composed of nine samples in core T2 (T2-1, 2, 3, 4, 5, 6, 7, 8 and 8.1), and also the upper part of biofacies PL, which is composed of nine samples in core T1 (T1-1, 2, 3, 4, 5, 6, 7, 8 and 10).

These sites were at the sandy coast, ranging from an outer bay to the open sea, near a river mouth, with water depths greater than 15–20 m, but shallower than biofacies LS. The percentage of those species that are common at water depths of more than 15–20 m in shallow sea areas around Japan (e.g., *A. obai*, *K. japonica*, *Ko. donghaiensis* and *A. nipponica*) are smaller in core T1 than in core T2. This indicates that the T1 site was in shallower water than the T2 site during this period.

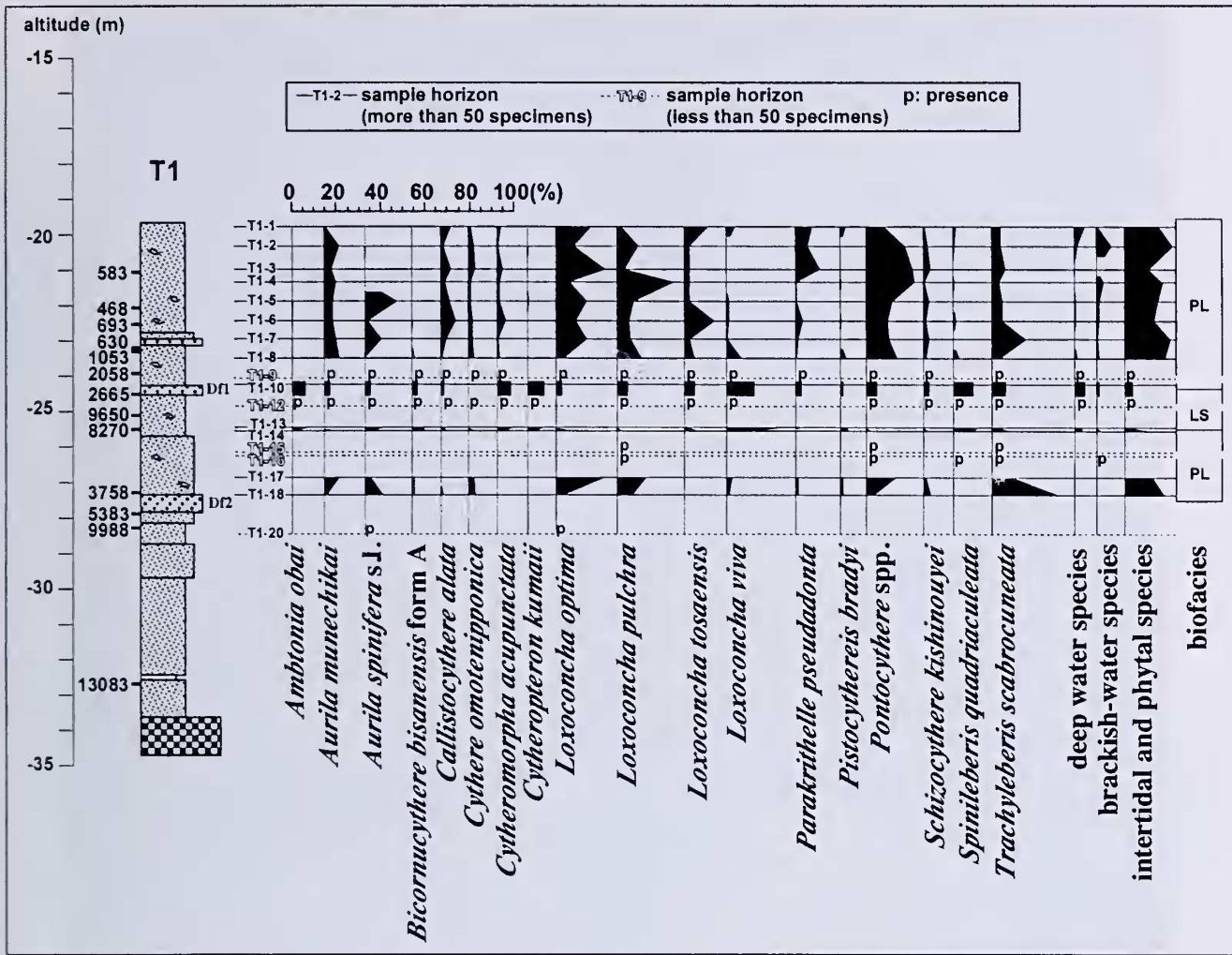


Figure 6. Columnar section of core T1, sample horizons, radiocarbon ages (cal yr B.P.), biofacies and percentages of dominant ostracode species. Deep-water, brackish, and intertidal and phytal species are similar to those in Figure 5.

In the Osaka Plain and the inner part of Osaka Bay, the relative sea-level change has been studied in detail on the basis of sedimentary facies, fossil ostracode faunas and high-density radiocarbon dating of molluscan shells (Miyahara *et al.*, 1999; Masuda *et al.*, 2000; Masuda and Miyahara, 2000; Irizuki *et al.*, 2001). These studies reported that the sea level rose rapidly from the period between ca. 11,000 cal yr BP to ca. 5,300–5,000 cal yr BP and from that time fell to the present sea level. The maximum sea level highstand was at ca. 5,300–5,000 cal yr BP in Osaka Bay (Masuda *et al.*, 2000). The historical changes in water depth at the two sites investigated in this study are similar to the relative sea-level changes proposed by Masuda *et al.* (2000), although the cores reveal areal differences in faunal changes during the same period. This result suggests that the relative sea-level curve of Masuda

et al. (2000) lends itself to the standard for relative sea-level change not only in Osaka Bay but also in more wide areas.

Systematic descriptions

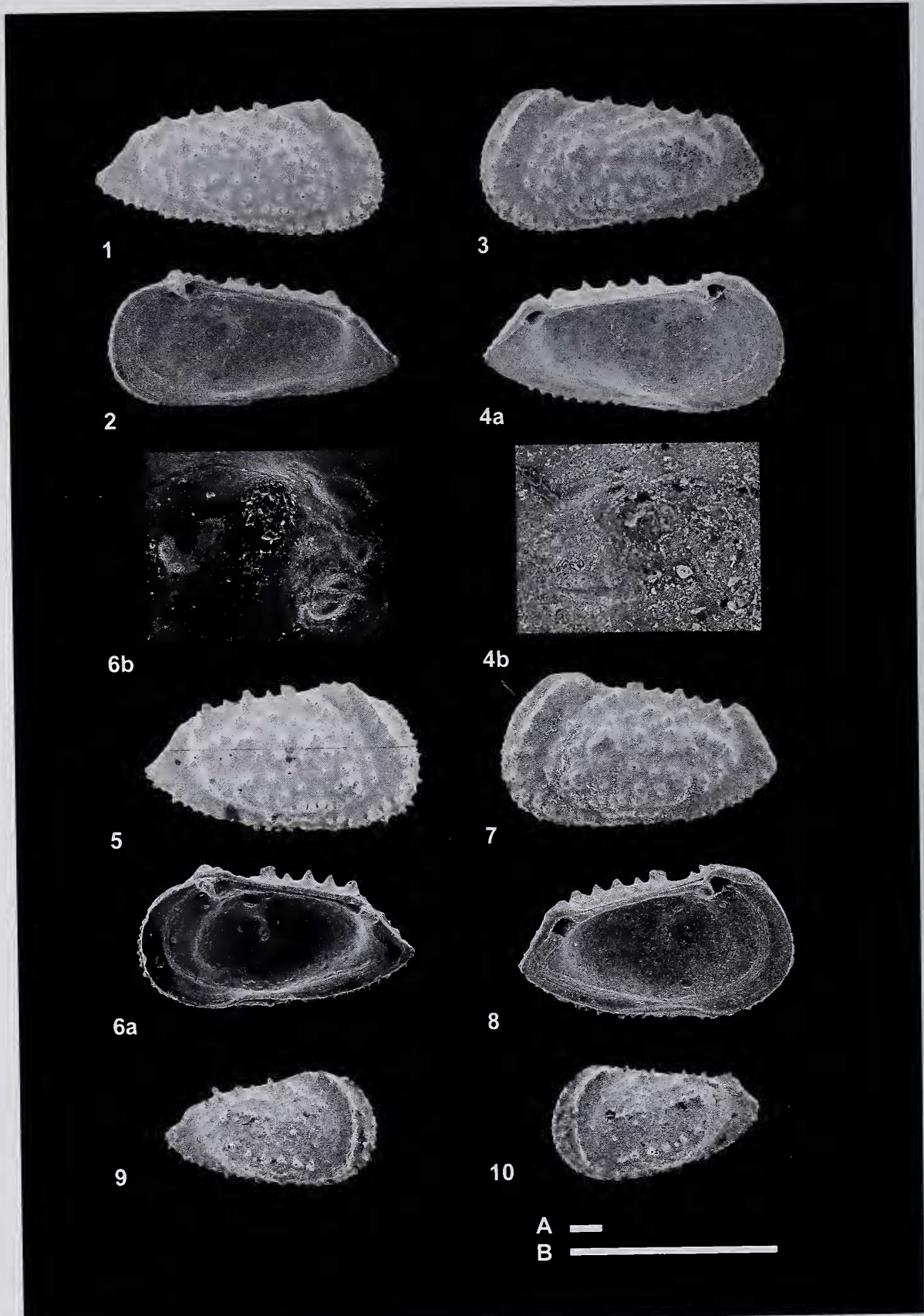
All the illustrated specimens are deposited in the collections of the Department of Biology and Geosciences, Graduate School of Science, Osaka City University (OCUCO).

Suborder Podocopina Sars, 1866

Superfamily Darwinuloidea Brady and Norman, 1889

Family Darwinulidae Brady and Norman, 1889

Genus *Darwinula* Brady and Robertson in Jones, 1885



Darwinula sp.

Figure 8.5–8.8

Materials.—20 specimens.*Diagnosis*.—*Darwinula* characterized by elongate and small carapace.*Occurrence*.—T1–2, 4–6, 8, T2–2 to T2–4, 6, 8, 10.*Remarks*.—This species has central muscle scars characteristic of darwinulids. This is the first fossil record of the genus from the Japanese Holocene. Ikeya and Hanai (1982) attributed a single broken valve from the Recent of Hamana-ko Bay, central Japan, to this genus. This genus has a freshwater habitat (Van Morkhoven, 1963).

Superfamily Cytheroidea Baird, 1850

Family Trachyleberididae Sylvester-Bradley, 1948

Subfamily Trachyleberidinae Sylvester-Bradley, 1948

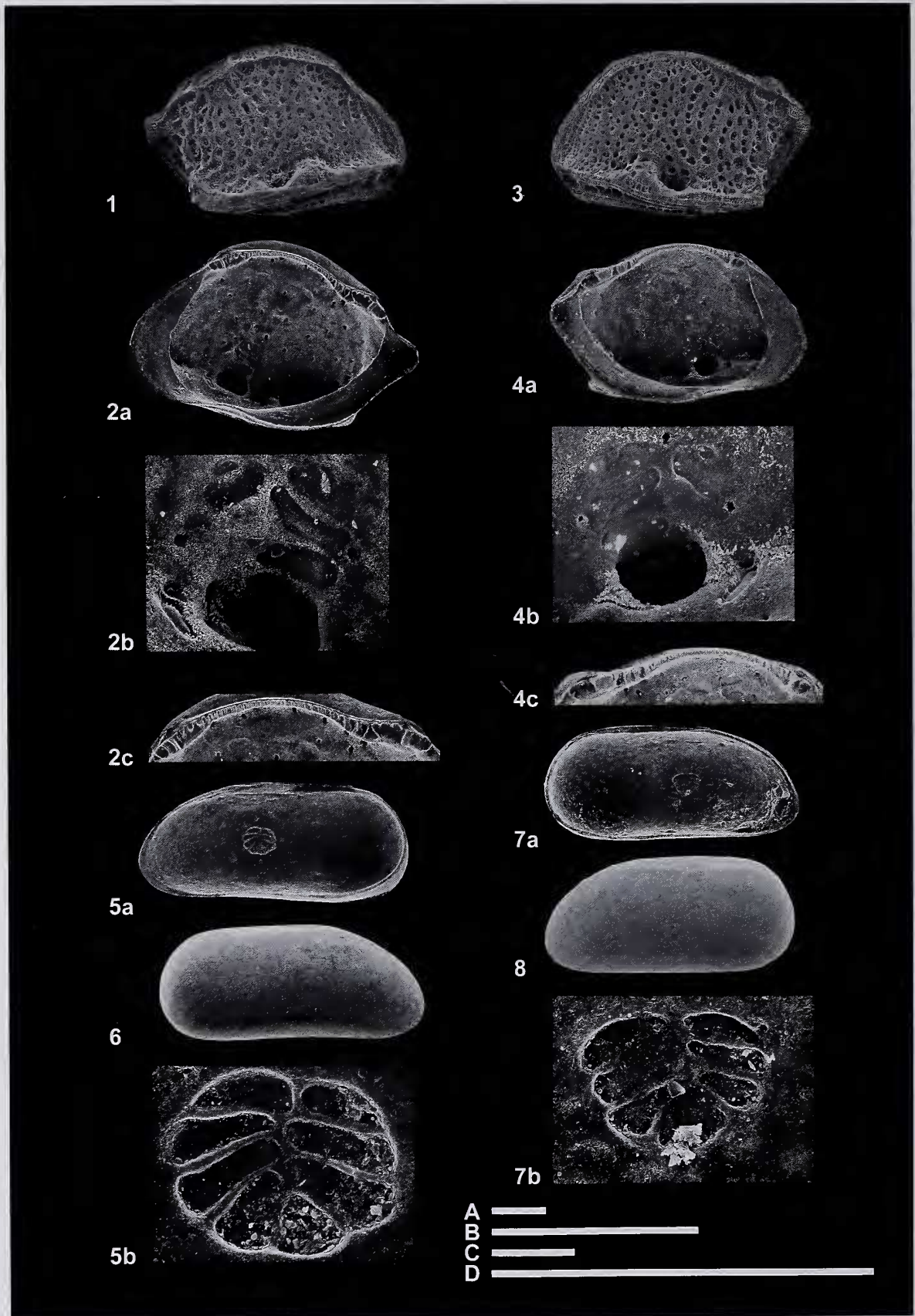
Tribe Trachyleberidini Sylvester-Bradley, 1948

Genus *Trachyleberis* Brady, 1898*Trachyleberis ishizakii* sp. nov.

Figure 7.1–7.10

Cythereis Yamigera [sic] (Brady). Kajiyama, 1913, p. 12, pl. 1, 64–66.*Trachyleberis scabrocuneata* (Brady). Ishizaki, 1969, p. 221–222, pl. 26, fig. 8; Ishizaki, 1971, p. 92–93, pl. 4, fig. 16; Okubo, 1979, p. 156, fig. 7a, b; Ikeya and Compton, 1983, p. 120, pl. 10–120, figs. 1a–4b, p. 126, pl. 10–126, figs. 1a–4b; Paik and Lee, 1988, p. 550, pl. 2, fig. 11; Ikeya and Itoh, 1991, p. 145, fig. 24, C; Kamiya and Nakagawa, 1993, p. 129, pl. 4, fig. 7; Ishizaki *et al.*, 1993, p. 329, fig. 7c; Irizuki *et al.*, 1998a, p. 7, fig. 2.13; Kamiya *et al.*, 2001, p. 103, fig. 18.18.*Cythere scabrocuneata* Brady. Puri and Hulings, 1976, p. 289, pl. 26, figs. 6, 8.*Trachyleberis* sp. 1. Ikeya and Suzuki, 1992, p. 137, pl. 9, fig. 4.*Actinocythereis* sp. Kamiya and Nakagawa, 1993, p. 129, pl. 4, fig. 8.*Trachyleberis* sp. Irizuki *et al.*, 2001, p. 109, fig. 3.8; Yasuhara and Irizuki, 2001, p. 95, pl. 12, figs. 9–13.*Etymology*.—In honor of Dr. Kunihiro Ishizaki.*Materials*.—86 specimens.*Diagnosis*.—*Trachyleberis* characterized by subtriangular valve shape, tubercles on valve surface, large dorsal tubercles and anterior marginal ridge.*Description*.—Carapace large, subtriangular, tapering posteriorly in lateral view, highest at anterior cardinal angle. Anterior margin broadly rounded and slightly extended below. Dorsal margin straight. Ventral margin broadly convex in female and straight in male. Posterior margin acuminate. Anterior, ventral and posterior margins fringed by spines and tubercles. Surface ornamented with tubercles, subcentral tubercle and anterior marginal ridge. Anterior marginal ridge running from anterior cardinal angle to midpoint of anterior margin. Eye and subcentral tubercles distinct. Pore canal openings moderate in number, scattered on most of valve surface. Pore canals with opening along edge of marginal contact zone of ventral marginal surface straight, numerous along anterior and posteroventral margins. Marginal infold moderate in width along anterior and posterior margins. No vestibule. Hinge holamphidont. Muscle scars consisting of one V-shaped frontal scar and a row of four adductor scars. Sexual dimorphism distinct; males more slender than females.*Types*.—Holotype, sample no. T1–6, OCUCO 0005, male RV, L = 0.884 mm, H = 0.420 mm (Figure 7.1); 9 paratypes, sample nos. T2–8.1, OCUCO 0006, T2–7, OCUCO 0007, T2–8, OCUCO 0008, T2–7, OCUCO 0009, T2–8.1, OCUCO 0010, T2–8.1, OCUCO 0011, T2–8, OCUCO 0012, T1–6, OCUCO 0013 and T1–6, OCUCO 0014.*Type locality*.—Holocene sediments off Wakayama City (34° 14.7' N, E 135° 5.2' E).*Occurrence*.—T1–2, 5–10, 13, 14, 18, T2–4 to T2–8, 8.1, 9, 10, 11–13.*Remarks*.—This species is similar to *Trachyleberis scabrocuneata* (Brady, 1880), but differs in having a shorter anterior marginal ridge, smaller carapace, straight margin broadly convex in male, larger dorsal tubercles, smaller number of surface tubercles and more slender shape. Also, this species is similar to *Trachyleberis niitsumai* Ishizaki, 1971, but differs in having a shorter anterior marginal ridge, more prominent and regular surface tubercles, larger dorsal tubercles and more slender shape.

← **Figure 7.** *Trachyleberis ishizakii* sp. nov. 1. Lateral view of male RV, holotype, T1–6, OCUCO 0005, L = 0.884 mm, H = 0.420 mm. 2. Internal view of male RV, T2–8.1, OCUCO 0006, L = 0.883 mm, H = 0.419 mm. 3. Lateral view of male LV, T2–7, OCUCO 0007, L = 0.869 mm, H = 0.447 mm. 4a, b. Internal view and muscle scars of male LV, T2–8, OCUCO 0008, L = 0.921 mm, H = 0.439 mm. 5. Lateral view of female RV, T2–7, OCUCO 0009, L = 0.848 mm, H = 0.463 mm. 6a, b. Internal view and muscle scars of female RV, T2–8.1, OCUCO 0010, L = 0.848 mm, H = 0.445 mm. 7. Lateral view of female LV, T2–8.1, OCUCO 0011, L = 0.848 mm, H = 0.476 mm. 8. Internal view of female LV, T2–8, OCUCO 0012, L = 0.852 mm, H = 0.480 mm. 9. Lateral view of A–1 stage RV, T1–6, OCUCO 0013, L = 0.656 mm, H = 0.359 mm. 10. Lateral view of A–1 stage LV, T1–6, OCUCO 0014, L = 0.641 mm, H = 0.362 mm. Scale bars are 0.1 mm: A for 1–4a, 5–6a and 7–10; B for 6b and 4b.



Family Cytheruridae G.W. Müller, 1894
 Subfamily Cytheropterinae Hanai, 1957
 Genus *Cytheropteron* Sars, 1866

Cytheropteron kumaii sp. nov.

Figure 8.1–8.4

Cytheropteron miurense Hanai. Ikeya and Itoh, 1991, p. 136, fig. 15, A.

Cytheropteron sp. Yasuhara and Irizuki, 2001, p. 79, pl. 4, fig. 10.

Etymology.—In honor of Prof. Hisao Kumai.

Materials.—80 specimens.

Diagnosis.—*Cytheropteron* characterized by subrhomboidal valve shape, small carapace and straight ventral alar process.

Description.—Carapace small, subrhomboidal in lateral view, highest at midlength. Anterior margin obliquely rounded. Dorsal margin strongly arched. Ventral margin sinuate, concave in middle, obscured in posterior third by alar process. Posterior margin protruding into a horizontally pointed caudal process. Surface ornamented with numerous reticula aligned more or less vertically, and dorsal and ventral marginal ridges. Reticula coarser in posterior half. Dorsal marginal ridge arcuate, very narrow, running along dorsal margin from anterior third to posterior terminal. Ventral marginal ridge starting from anterior end and running along ventral margin to form a prominent anterior edge of alar process. Eye tubercle indistinct. Pore canal openings moderate in number, scattered on most of valve surface. Pore canals with openings along edge of marginal contact zone of ventral marginal surface few, approximately ten along anterior margin. Marginal infold moderate in width along anterior and posterior margins. Vestibule poorly developed along anterior margin, broadest at anteroventral margin. Hinge line sinuous in interior view. Hinge of right valve consists of anterior and posterior teeth and an intermediate groove. Intermediate groove subdivided into three parts: short anterior part with three large crenulations, finely crenulate median part and concave posterior part with six small sockets, of which the anterior three are clearly separated and the posterior three are connected to each other. Hinge of left valve complementary of that of right valve. Muscle scars consist of two frontal scars, of which upper scar is smaller and lower scar is elongate, and a row of four elongate adductor scars.

Sexual dimorphism indistinct.

Type and Dimensions.—Holotype, sample no. T2-12, OCUCO 0015, adult LV, L = 0.482 mm, H = 0.313 mm (Figure 8.3); 3 paratypes, sample nos. T1-12, OCUCO 0016, T1-12, OCUCO 0017 and T2-12, OCUCO 0018.

Type locality.—Holocene sediments off Wakayama City (34° 14.5' N, 135° 5.2' E).

Occurrence.—T1-2, 5, 10, 12-14, T2-4 to T2-7, 8.1, 9, 10, 11-13, 13.1.

Remarks.—This species is similar to *Cytheropteron miurense*, but differs in having a thinner alar process and finer and larger amount of surface ornamentation.

Conclusions

1. Before ca. 7,000 cal yr BP, site T2 ranged from a bay coast to an outer bay, near a river mouth, at water depths of less than 15–20 m, and site T1 was a sandy coast, ranging from an outer bay to the open sea, near a river mouth, at water depths of more than 15–20 m, but shallower than biofacies LS.

2. From ca. 7,000–2,000 cal yr BP, the two sites varied in condition from an outer bay to the open sea at water depths of 30–40 m, where they were strongly influenced by the residual and/or tidal currents from the strait.

3. After ca. 2,000 cal yr BP, the two sites were situated along a sandy coast, ranging from an outer bay to the open sea, near a river mouth, at water depths of more than 15–20 m, but shallower than biofacies LS. Site T1 was shallower than site T2 during this period.

Acknowledgements

We would like to thank Kunihiko Ishizaki of Ishinomaki Senshu University for critical reading of the manuscript, and Hisao Kumai of Osaka City University for advice and continuous encouragement throughout the course of the present study. We also thank Hisao Ishii and Yoko Ishii of the Osaka Museum of Natural History for permission and assistance to access the drilling core samples, and Takamoto Okudaira of Osaka City University for providing permission to use and instruction in the operation of the scanning electron microscope (JEOL JSM-5500) in his laboratory. Anonymous reviewers improved the paper considerably.

◀ **Figure 8.** 1–4, *Cytheropteron kumaii* sp. nov. 1. Lateral view of adult RV, T1-12, OCUCO 0016, L = 0.482 mm, H = 0.326 mm. 2a–c. Internal view, muscle scar and hinge of adult RV, T1-12, OCUCO 0017, L = 0.530 mm, H = 0.349 mm. 3. Lateral view of adult LV, holotype, T2-12, OCUCO 0015, L = 0.482 mm, H = 0.313 mm. 4a–c. Internal view, muscle scars and hinge of adult LV, T2-8, OCUCO 0018, L = 0.474 mm, H = 0.299 mm. 5–8, *Darwinula* sp. 5a–b. Internal view and muscle scars of adult RV, T2-8, OCUCO 0001, L = 0.494 mm, H = 0.226 mm. 6. Lateral view of adult RV, T2-4, OCUCO 0002, L = 0.487 mm, H = 0.227 mm. 7a–b. Internal view and muscle scars of adult LV, T1-2, OCUCO 0003, L = 0.469 mm, H = 0.222 mm. 8. Lateral view of adult LV, T2-4, OCUCO 0004, L = 0.462 mm, H = 0.226 mm. Scale bars are 0.1 mm: A for 1–2a, 3–4a, 5a, 6, 7a and 8; B for 2b and 4b; C for 2c and 4c; D for 5b and 7b.

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